Treating wastewater as an alternative resource in concrete manufacturing to address water shortage in construction: a review

Sarika P. Thombare[1*], *Arun Kumar* Dwivedi[2], and *Ashwini* Patil[3]

[1] Research Scholar, Sandip University, Nashik, and Assistant Professor, Ajeenkya DY Patil School of Engineering, Lohegaon, Pune, Maharashtra, India
[2] Assistant Professor, Sandip University, Nashik 422213, Maharashtra, India
[3] Assistant Professor, D. Y. Patil School of Engineering, Akurdi, Pune, Maharashtra, India

Abstract. Freshwater demand is rising worldwide while available supplies grow scarcer. Concrete production consumes large volumes of freshwater for mixing, curing and washing, and rapid industrial growth has placed further stress on water resources. This review examines how the characteristics of different wastewaters affect their reuse as a substitute for potable water in concrete. It summarises the physical and chemical properties of municipal, industrial, grey and other wastewaters and their effects on the workability, setting time, strength, durability and microstructure of concrete, and it considers the treatment methods, costs and policy needs involved. The evidence shows that wastewater can lower the workability of fresh concrete, yet treated water can still give acceptable strength and long-term performance. Treated greywater reduced compressive strength by about 5 to 8 percent, treated domestic wastewater improved workability by about 10 percent, and water reuse achieved cost savings of up to about 12 percent. Reclaimed and tertiary treated wastewater performed better than secondary or industrial wastewater. With adequate treatment, monitoring and standards, wastewater reuse can conserve freshwater and support more economical and ecofriendly concrete construction.

Keywords: concrete; wastewater; compressive strength; hardened properties; durability; water scarcity.

1 Introduction

1.1 Water scarcity in construction

The population and the construction sector in India are both growing rapidly, and concrete is central to almost all of this construction.

* Corresponding author: sarika9922@gmail.com

Concrete production depends on potable water, yet water shortages, especially during the summer, have become a serious concern in many parts of the world. Large volumes of wastewater are discarded every day and are rarely used for anything other than irrigation. If this water were treated and reused, it would ease the pressure on freshwater supplies. Part of the organic and microbial load in wastewater can be reduced during cement hydration, which makes treated wastewater a candidate for non structural and residential concrete, while also lowering the volume of effluent discharged to rivers [1, 2].

All living systems depend on water, and human activity relies heavily on freshwater. Freshwater makes up less than one percent of the water on Earth, and about half of it is held in glaciers, so only a small fraction is readily accessible [1]. Much of the remaining freshwater lies underground or is otherwise unusable. As a result, billions of people face water scarcity for at least part of the year, and inadequate access to clean water and sanitation continues to cause preventable disease in many regions [2].

The construction industry is among the sectors most affected by drought, because concrete mixing, curing, dust suppression and equipment cleaning all require a steady water supply. The problem is more severe in arid regions and during prolonged droughts, when agriculture, industry and households compete for the same limited supply. Climate change, population growth, urbanisation and the overuse of existing sources are together reducing freshwater availability and raising the risk of project delays. In response, regulatory and environmental bodies are encouraging the industry to adopt water efficient practices such as water recycling, rainwater harvesting and the use of materials that need less water.

Concrete consumes large quantities of water, since a single cubic metre requires substantial volumes for mixing, curing and cleaning. Growing freshwater scarcity therefore threatens the sustainability of using potable water for concrete. Recycled water, chemical admixtures and supplementary cementitious materials are increasingly used to lower both the water demand and the environmental impact of concrete [3, 4].

1.2 Wastewater as an alternative resource

The large-scale discharge of domestic and commercial wastewater, together with its reprocessing for construction, is becoming a practical option. Global water demand is rising with climate change, which will further reduce freshwater availability, so treated wastewater is a viable alternative for easing water scarcity. Advanced treatment can raise wastewater to the quality needed for mixing, curing and dust suppression. Using it in construction would reduce both the freshwater consumed by the concrete industry and the volume of effluent released to the environment, which supports the sector's move towards a circular and sustainable model [5, 8].

The main objectives of using treated wastewater in concrete are to recognise it as an alternative source of mixing and curing water, to treat it adequately so that it does not pollute the environment, to reduce the overall cost of concrete where treated wastewater is cheaper than freshwater, to ensure that its use does not compromise the strength, durability or safety of concrete, and to keep the approach operationally and administratively feasible rather than purely theoretical.

2 Review of literature

Building on the case for wastewater reuse, this section reviews the empirical literature on alternative water sources and waste derived materials in concrete and water management. Sales, de Souza and Almeida [2] showed that a composite of water treatment sludge and sawdust gave good mechanical properties in concrete. Meena and Luhar [3] reported that concrete made directly with untreated wastewater suffered reduced strength and durability, whereas Morgado et al. [4] found acceptable performance for concrete made with treated wastewater and recycled aggregates. Shaikh and Inamdar [5] and Gaikwad et al. [6] confirmed that sewage treated water can serve as an alternative mixing water in concrete. In a systematic review, Silva [7] concluded that wastewater reuse is important for the sustainable use and planning of water supplies, and Cosgrove and Loucks [1] set out the main global water management challenges and research directions.

Several studies have examined the economic, technical and feasibility aspects of treated wastewater. Grace, Clifford and Healy [8] showed that waste products from various sectors can support water treatment, while Molinos-Senante [9] and Kalbar, Karmakar and Asolekar [10] applied economic and decision-making approaches to select suitable treatment technologies. Improvements in treatment efficiency have been reported for urban plants in China [11] and in pilot scale sequencing batch reactor studies [12]. Research has also linked wastewater management to the circular economy and energy recovery: Gomes et al. [13] reviewed the recycling of water treatment sludge into building materials, and Zarei [14] and Ahmed et al. [15] discussed the integration of wastewater reuse into sustainable resource cycles. Overall, the literature gives limited attention to the use of real, as opposed to simulated, wastewater in concrete, which points to a need for further investigation.

3 Types of wastewater suitable for concrete manufacturing

Several categories of wastewater can be reused in concrete once they meet the required quality limits. Municipal effluent from domestic sewage treatment plants can be used when organic pollutants, heavy metals and bacteria have been removed and the pH, sulphate and chloride levels are checked regularly. Recycled concrete wash water, generated at batching plants and construction sites, can be reused after the solids are allowed to settle. Industrial wastewater from food processing, beverages, textiles, tanneries, mining, dairy and metal works can be reused only after rigorous primary, secondary and tertiary treatment. Stormwater and rooftop or paved area runoff is usually only lightly polluted and needs little or no treatment before mixing, although its quality is not guaranteed. Desalination reject water has a high salt content and should not be used in reinforced concrete unless the salinity is first reduced, because the salts can corrode steel. Agricultural runoff can be used once fertilisers and other chemicals are removed by suitable treatment. Greywater from showers, sinks and laundry can replace freshwater after soap, oil and organic matter are removed, which is particularly useful in water scarce areas [8].

4 Quality standards and assurance

The reuse of wastewater in concrete must comply with recognised standards so that the quality, durability and safety of the concrete are not compromised. Mixing water is commonly assessed against IS 456, ASTM C94 and EN 1008, which set limits on parameters such as pH, chloride, sulphate and total dissolved solids. However, these standards were written mainly for potable or conventional mixing water, and specific guidance for treated wastewater remains limited. This gap should be addressed through dedicated acceptance criteria and routine testing.

5 Effect of wastewater on fresh properties of concrete

5.1 Workability

Workability governs how easily concrete can be placed and compacted, and poor compaction leaves voids that reduce strength. Slump tests on mixes made with different proportions of sewage water show that the slump falls as the water to cement ratio and the sewage content increase, because fine particles in the water absorb part of the mixing water. Industrial wastewater has been reported to reduce the slump by about 12.5 percent, and dissolved particles in both raw and treated greywater lowered the slump by about 30 to 35 mm. In general, wastewater reduces workability relative to potable water, and the reduction grows with the fines content and surface area of the suspended solids [4, 7]. Chlorination of the mixing water did not change the slump but lengthened the setting time. For treated effluents from a palm oil mill, domestic sewage and heavy industry, the reported slump values were consistently lower than those of comparable potable water mixes, and depended strongly on the source and treatment level of the water.

5.2 Setting time

The level of treatment also affects the setting time. Physical methods such as screening and sedimentation remove large particles, but dissolved solids and organic matter can remain. Organic contaminants and suspended particles slow cement hydration by reducing the rate of the hydration reactions, which lengthens the setting time. Primary treated wastewater tends to give the longest setting times, while secondary and tertiary treated water behaves more like freshwater. Tertiary treatment, which adds chemical coagulation, filtration and ultraviolet disinfection, removes most of the remaining nutrients, pathogens and suspended solids and raises the water to a quality suitable for construction. Treated wastewater generally prolongs the initial and final setting times slightly, whereas recycled wash water can shorten them. Overall, tertiary treated wastewater is the most suitable for concrete, because its effect on setting and hydration is closest to that of freshwater.

6 Effect of wastewater on hardened and durability properties

6.1 Strength and penetration

Table 1 compares the compressive strength, split tensile strength and water penetration reported for concrete made with different mixing waters. The compressive strength ranged from about 27 to 32 MPa and the split tensile strength from about 2.3 to 2.8 MPa, with penetration depths between 65 and 72 mm. In general, the higher strength mixes showed lower penetration, which indicates a denser and more durable matrix.

Table 1. Comparison of strength parameters and water penetration for different mixing waters.

Water type	Compressive strength (MPa)	Split tensile strength (MPa)	Penetration (mm)	Penetration rating
M1	32	2.8	65	Moderate
M2	30	2.5	68	Low
M3	31	2.6	70	Moderate
M4	27	2.3	72	Low

6.2 Durability

Durability is often limited by sulphate and acid attack. Concrete made with treated wastewater showed improved resistance to chloride ingress over time, with lower measured values after 56 days. Water absorption, which is an indicator of durability, was also affected by the mixing water: mixes made entirely with wastewater showed lower surface absorption after 120 minutes, while a 25 percent replacement increased absorption at early ages. Over time, all mixes met the accepted durability limits. Lower water absorption and higher electrical resistivity both indicate a more durable concrete.

7 Risks, mitigation and policy considerations

7.1 Risks

The quality of wastewater is not constant; it varies with the season and with nearby industrial activity, which in turn affects concrete performance. Microbial contamination can damage the concrete and spoil its finish, dissolved salts can cause scaling and damage equipment, and chlorides or sulphates can corrode steel reinforcement over the long term. Poorly managed effluent also poses environmental and safety hazards, since incorrect disposal can contaminate soil and water. Even treated wastewater carries residual impurities that can gradually reduce the resistance of concrete to chemical attack.

7.2 Mitigation

Several measures can reduce these risks. Standardised treatment steps such as filtration, ion exchange and ultraviolet disinfection help maintain a consistent water quality, and routine monitoring against ASTM C94 or EN 1008 keeps the water within acceptable limits. Admixtures, protective coatings and supplementary cementitious materials such as fly ash, silica fume and slag improve durability, and regular long term performance testing confirms that the structure remains sound.

7.3 Policy and public awareness

Mainstream adoption of wastewater reuse will require strong policy support. Regulations should set clear water quality standards and test methods, and building codes should include provisions for wastewater reuse, on site treatment and continuous monitoring. Tax credits, subsidies and reduced permit fees would encourage uptake, and international coordination of standards would spread good practice more quickly. Policy alone is not enough, however, since public awareness is equally important. Workshops, media campaigns and demonstration projects can build trust by showing the environmental and economic benefits and including sustainability in education helps develop awareness from an early stage. Provisions that promote reuse for mixing, dust control, landscaping and cleaning, together with dual plumbing, make reuse feasible in practice. Persistent challenges include variable water quality, the presence of sulphates, chlorides, heavy metals and organic matter, the absence of dedicated standards, and the higher cost and complexity of mix design and quality control, as well as safety concerns and public perception.

8 Conclusions and future scope

Treated wastewater can be used to make concrete and thereby reduce the demand for freshwater, lower production costs and reduce environmental impact, and in some cases it can improve early age strength and workability. When treated to the levels required by IS 456, such water can produce concrete with a compressive strength comparable to that made with ordinary tap water. Scaling up this practice, with adequate treatment, monitoring and regulation, could conserve significant volumes of water and support more sustainable construction.

Future work should focus on developing broad standards and regulations for water reuse in concrete, optimising mix designs, testing long term durability under real site conditions, and improving pretreatment technologies so that the effluent remains safe for use. Field scale pilot studies are needed to identify practical barriers and to build confidence in the approach, and economic analysis, incentives and training can support wider uptake. Progress will ultimately depend on cooperation between researchers, industry and regulators.

Declaration of interest: The authors declare no conflict of interest.
Funding: This research received no external funding.

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